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Enhancing Lean-Kaizen practices through IoT and automation: A comprehensive analysis with simulation modeling in the Thai food industry

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Abstract

This research delves into a comprehensive examination of the noodle production process within the Thai food industry, focusing on pivotal challenges related to quality control during steaming, weighing, sealing, and vacuum packaging. In response to these challenges, our study investigates the strategic integration of Internet of Things (IoT) and automation solutions to amplify production efficiency. Employing advanced plant simulation tools, including lean manufacturing and Kaizen principles, coupled with methodologies like value stream mapping and flow process charts, we explore four distinct improvement scenarios. Scenario 1 targets enhancements in the dough-baking system during the steaming process, while Scenario 2 concentrates on optimizing the boiler control system. Scenario 3 addresses the weighing and packing process, and Scenario 4 aims at automating the packing process. These scenarios collectively showcase substantial reductions in cycle time, labor costs, and improvements in production capacity. The research design spans a 30-day data collection period, capturing critical metrics related to cycle time, changeover time, workforce, lead time, value-added time, and inventory levels. The gathered data unveils inefficiencies and challenges within the noodle production process, offering a foundation for identifying bottlenecks and areas for enhancement. The study's outcomes underscore the efficacy of technology-driven solutions in addressing production challenges and boosting operational efficiency. Specifically, Scenario 1 and Scenario 4, integrating IoT technology and automation, exhibit a remarkable 7.8% increase in productivity with a one-year payback period. Meanwhile, Scenario 3 significantly reduces labor costs and enhances overall efficiency. These findings contribute to the broader industry discourse, emphasizing the transformative potential of technology-driven solutions in addressing key production challenges and advancing operational excellence. The research provides valuable insights for practitioners seeking innovative approaches to enhance their processes and embrace Industry 4.0 advancements.

Keywords: Simulation modeling, Noodle production process, Lean-Kaizen, Internet of Things, Automation

1. Introduction

The Thai Food Industry, celebrated for its diverse culinary offerings and economic significance, grapples with the ongoing challenge of optimizing production processes while ensuring the consistent delivery of high-quality products. The Noodle Production Process, a complex operation known for its stringent quality control prerequisites, faces persistent issues, particularly during the steaming, weighing, and sealing processes [1]. Responding to these challenges, the industry increasingly adopts transformative technologies such as the Internet of Things (IoT) and automation, offering the potential to overhaul production processes, enhance efficiency, and uphold stringent quality standards [2].

The integration of IoT and automation technologies in the food industry has garnered significant attention in recent years, providing potential solutions to challenges related to quality control and production efficiency. Insightful research articles highlight the application and impact of these technologies. IoT has been utilized for real-time data collection and quality control in food processing, as demonstrated by studies from Maroli et al. [1] and da Costa et al. [2], encompassing temperature monitoring, humidity control, and equipment status tracking. Automation, emphasized in the work of Heema et al. [3], plays a crucial role in reducing human errors and enhancing production efficiency, particularly in weighing and packaging operations.

Simulation modeling, illustrated by Zúñiga et al. [4], has been applied across various industries to identify inefficiencies and optimize processes, aligning with Lean Manufacturing and Kaizen principles. The effectiveness of Lean Manufacturing and Kaizen in improving manufacturing operations is underscored by studies such as Maware et al. [5] and Ortiz and Cárdenas [6], emphasizing the reduction of waste and enhanced productivity.

Rejeb et al. [7] and Firouz et al. [8] delve into the application of IoT and automation in the food industry, addressing quality control and traceability in food production and the impact of automation on packaging processes. The integration of IoT, automation, and

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simulation modeling is explored in studies like Jiang [9], highlighting their synergy in enhancing the efficiency of food production processes.

The literature points to a growing trend in applying IoT, automation, and simulation modeling in the food industry to address quality control issues and improve production efficiency. These technologies, coupled with Lean Manufacturing and Kaizen principles, hold the potential to revolutionize the optimization and validation of food production processes, as demonstrated in the Thai Food Industry's Noodle Production Process. To address the dual challenges of process optimization and quality control, simulation modeling has emerged as a potent tool, demonstrating promise in pinpointing inefficiencies and enhancing production processes within the Thai Food Industry [10].

Supported by advanced software tools like Plant Simulation and Visual Component, simulation modeling allows the creation of innovative solutions to tackle industry-specific challenges [11, 12]. Complementing these advancements are the principles of Lean Manufacturing and Kaizen, consistently enhancing operational efficiency in various manufacturing settings [13, 14]. In recent years, there has been a surge of interest in integrating IoT into industrial processes, including food production [15]. IoT applications offer real-time data collection, monitoring, and control, making them particularly attractive for addressing quality control issues in food production [16]. Automation has proven effective in streamlining production processes within the food industry, particularly through the automation of weighing, packaging, and sealing operations [17, 18].

In summary, the literature review underscores the significance of integrating IoT, automation, and simulation modeling, complemented by Lean Manufacturing and Kaizen principles, (as shown in Table 1) to address challenges in optimizing production processes and ensuring quality control within the food industry. The diverse studies contribute to a comprehensive understanding of the potential solutions available and pave the way for the unique exploration presented in this research.

This paper embarks on a distinctive exploration, seeking to synergize simulation modeling, IoT, and automation technologies within the context of the Thai food industry's noodle production process. Four distinct scenarios are examined for their potential to elevate production efficiency, culminating in the selection of an innovative approach by industry entrepreneurs. This approach, as detailed in subsequent sections, has the potential to revolutionize production and quality control practices within the Thai food industry.

Table 1 Summary of Research Background and Literature Review

Author and Year	Focus of Study	Key Findings
Maroli et al. [1]	IoT in real-time data collection and quality control in food processing	Emphasizes the use of IoT for temperature monitoring, humidity control, and equipment status tracking, contributing to improved production quality.
da Costa et al. [2]	IoT in real-time data collection and quality control in food processing	Demonstrates the application of IoT in enhancing food processing efficiency by monitoring critical parameters.
Heema et al. [3]	Automation in weighing and packaging operations	Highlights the impact of automation in reducing human errors and enhancing production efficiency, specifically in weighing and packaging processes.
Zúñiga et al. [4]	Simulation modeling for operational efficiency	Illustrates the use of simulation modeling to enhance operational efficiency and validate process improvements, aligning with Lean Manufacturing and Kaizen.
Maware et al. [5]	Lean Manufacturing principles	Emphasizes the role of Lean Manufacturing principles in reducing waste and enhancing overall productivity in manufacturing settings.
Ortiz and Cárdenas [6]	Lean Manufacturing and Kaizen principles	Highlights the effectiveness of Lean Manufacturing and Kaizen in improving operations, reducing waste, and increasing productivity.
Rejeb et al. [7]	IoT and automation in quality control and traceability	Explores the use of IoT for quality control and traceability in food production, shedding light on the impact of automation on packaging processes.

In light of these considerations, this paper establishes objectives to guide the exploration and analysis: 1) Investigate the application and impact of IoT and automation technologies on quality control and production efficiency in the food industry. 2) Explore the role of simulation modeling, supported by Lean Manufacturing and Kaizen principles, in pinpointing inefficiencies and enhancing production processes and 3) Evaluate four distinct scenarios for their potential to elevate production efficiency and propose an innovative approach for industry entrepreneurs. These objectives aim to provide a comprehensive understanding of the challenges and opportunities in optimizing production processes and ensuring quality control within the Thai Food Industry.

2. Materials and methods

2.1 Research flow charts

The sequential process flow diagram, as depicted in Figure 1, has been methodically implemented within the operations division. Following a structured approach, the study adhered to six essential steps as guidelines for the application of Value stream mapping (VSM) tools. These steps encompassed the comprehensive assessment of the existing situation, the systematic execution of the process flow, and the meticulous mapping of the current state. Subsequently, a deep dive into operational inefficiencies identified areas within the production cycle categorized as non-value added (NVA) activities. These inefficiencies were further classified into seven distinct categories, in line with Lean-Kaizen principles. The analysis also involved a critical assessment of operational challenges, exploration of potential solutions, particularly in the realm of IoT and automation, and the subsequent evaluation and approval of feasible ideas.

This holistic approach provided a structured framework for the thorough examination and enhancement of operational processes within the operations division, aligning with Lean-Kaizen principles and exploring innovative solutions.

Furthermore, this comprehensive framework facilitated the critical evaluation of each operational activity, contributing to a holistic assessment of the workflow. By adhering to these established steps, the study ensured a systematic and structured approach to process improvement, allowing for the identification of inefficiencies, classification of wastes, and exploration of modern solutions such as IoT and automation. In essence, this approach formed the backbone of the study's efforts to optimize and streamline operations within the operations division, ultimately fostering an environment of efficiency and innovation.

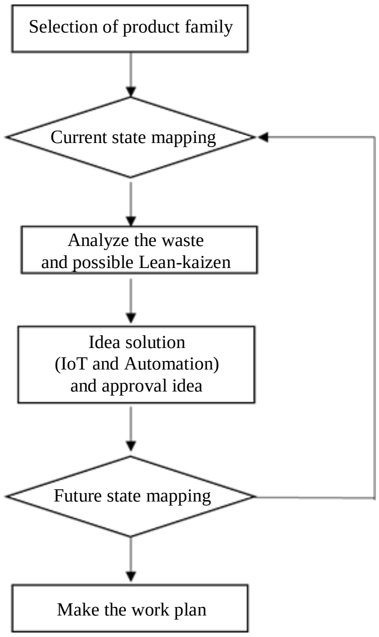

Figure 1 Flowchart showing six steps of VSM.

2.2 Manufacturing organization profile

AAA Enterprises is a well-established small- to medium-sized manufacturing organization based in a non-capital region of Thailand. The company operates within the food manufacturing sector, with a particular focus on the production of a variety of food products, including the popular staple, noodles packing 1 kg., as illustrated in Figure 2. AAA Enterprises serves both retail and wholesale markets, distributing its products throughout the region.

In terms of its workforce, AAA Enterprises maintains a dedicated team of around 50 employees, working diligently to ensure the company's production runs smoothly. The workforce is organized into two shifts, each spanning 8 hours, allowing for continuous production and operational efficiency. This strategic scheduling helps AAA Enterprises meet the demands of its diverse customer base while maintaining quality standards.

The location of AAA Enterprises in a non-capital region of Thailand highlights its commitment to serving local communities and contributing to the regional economy. As a regional manufacturing player, AAA Enterprises plays a significant role in not only providing quality food products but also generating employment opportunities and supporting economic growth in the area. This organizational profile sets the stage for further exploration into AAA Enterprises' unique operational challenges, its strategies for enhancing production efficiency, and the integration of modern technologies such as IoT and automation in the context of the Thai food industry.

2.3 Present work

In this study, we conducted a meticulous case study applying the Lean-Kaizen concept, focusing on the use of the Value stream mapping (VSM) tool within the selected company. Guided by the fundamental principles of lean manufacturing [19, 20], we employed traditional pencil and paper methods, utilizing a well-defined set of visual icons. These symbols served to depict the intricacies of the production line for the specific product under investigation, underscoring our commitment to a thorough analysis and the practical application of Lean-Kaizen principles for enhancing overall operational efficiency.

2.4 Data correction

Data collection for this study involved a 30-day period of on-site visits to the company. During these visits, a range of crucial data points, including cycle time (C/T), changeover time (C/O), shift counts, workforce size, lead time, and value-added time, were meticulously recorded. Furthermore, the study encompassed the collection of data regarding the monthly and daily product requirements, product movement, as well as work-in-progress (WIP) and inventory levels. The collected dataset underwent thorough analysis, revealing concerning aspects within the process, notably high rates of rework, rejection, and an accumulation of inventory related to the product.

Figure 2 Displays the packaging of one kilogram of noodles.

2.5 Current state map

The current state map serves as a visual representation of the existing operational processes, offering valuable insights into areas for potential improvement. The illustration of the current state, as depicted in Figure 3, reveals a structured framework in which upstream interactions with suppliers and downstream interactions with customers are intrinsically linked through the shipment department. Within this depiction, the upper section signifies the information flow, which traverses from right to left between customers and suppliers. In contrast, the lower section represents the material flow, moving from left to right along the production line. The production line comprises six core processes, specifically Soak &Grind, Preparation, Steaming, Retrogradation, Slicing, and Packaging. The procurement of raw materials occurs monthly, with weekly deliveries. Consequently, the inventory level of raw materials is maintained at a one-day supply, contributing to an extended lead time. Furthermore, the engineering and production planning and control department engages in a weekly scheduling of each process via work orders, receiving production quantity updates from the production supervisor. This system has exposed a communication gap between individual workstations.

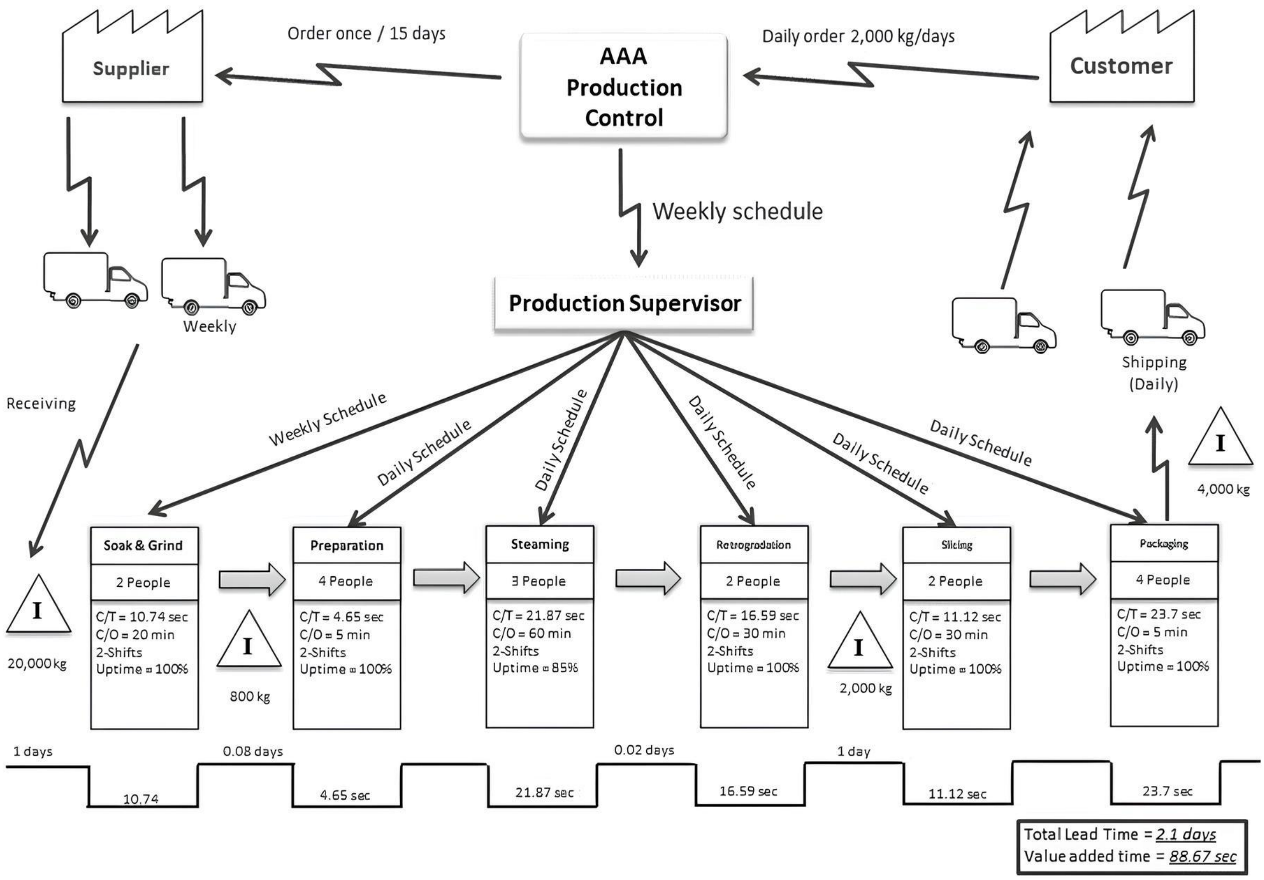

Figure 3 Current state map

The overall production system operates on a push mechanism, leading to an accumulation of work-in-progress (WIP) across multiple work areas. The computed production lead time is 3.08 days, while the value-added time is measured at 93 minutes. These temporal aspects are visually depicted in a timeline presented at the bottom of the current map. The cycle times for each process have been calculated based on actual data collected. Notably, the Streamer process stands out with a high cycle time of 20 minutes, attributed to an elevated rejection rate. This process, marked as a bottleneck, experiences substantial WIP levels. Inventory storage points between processes are symbolized by triangular markers.

The cumulative timeframe required for the entire process, denoted as the total duration or the total time of the entire substation, stands at 88.67 seconds per kilogram of the product shown as Table 2.

Table 2 Production process and cycle times at each workstation for noodle production

Workstation	Name	Process	Cycle time (sec)	
1	Soak & Grind	Cleaning rice	0.94	10.74
		Soaking rice	5.24	
		Grinding rice	4.56	
2	Preparation	Starch Preparation	4.65	4.65
3	Steaming	Steamed Noodles	21.87	21.87
4	Retrogradation	Receiving and rolling the noodle sheets	13.35	16.59
		Noodles retrograde	3.24	
5	Slicing	Lift the noodle sheets into the shredder	2.21	11.12
		Slicing noodles	8.02	
		Noodles flow onto the packing table	0.89	
6	Packaging	Weigh the noodles to 1 kg	5.64	23.7
		Vacuum sealing	18.06	
			Total	**88.67**

2.6 Takt time and productivity calculation

During this study, several assumptions were considered, notably the exclusion of variations in operational skills and shifts for the purpose of calculations. The company's standard operational schedule comprises two daily shifts, each spanning 8 hours, with a monthly customer demand for noodles averaging 60,000 kg. When accounting for 25 effective working days per month, accounting for exceptions like four Sundays and one holiday, the daily customer demand was found to be 2,000 kg. Deducting lunch breaks of 60 min and two 20-min tea breaks per shift from the average working time of 380 min, the available daily working time was computed as 45,600 sec. The calculation of takt time is detailed as follows Equation (1) below,

$$Takt\ time = \frac{available\ working\ time\ per\ day\ in\ seconds}{customer\ demand\ per\ day\ in\ kg} \quad (1)$$

The derived takt time signifies that AAA Company must achieve a production rate of one workpiece every 22.80 to align with customer demand, underscoring the imperative to optimize production processes accordingly.

The cycle time surpasses the production takt time, indicating that the packaging station is operating at a rate insufficient to meet customer demand, necessitating overtime work. Within the noodle production process encompassing six workstations, the cycle time is found to be 23.70 seconds per kilogram, with specific reference to the packaging station. Additionally, according to data from Table 2, the total substation time stands at 88.67 seconds per kilogram. This data forms the basis for assessing the efficiency of the noodle production line prior to any enhancements, as we apply the values within equation (2) as follows,

$$Productivity = \frac{Total\ time\ of\ all\ subwork\ stations * 100}{Number\ of\ workstations * actual\ cycle\ time} \quad (2)$$

Therefore, the Productivity of the noodle production line before the improvement was 62.35 %.

2.7 Importing data into simulation models

The researchers developed an extensive questionnaire for the workers, serving as a foundation for their subsequent model. Following a meticulous analysis of the questionnaire responses, the team identified distinct categories that shaped the inputs and outputs of the simulation model. Under deterministic inputs, which are controllable factors influencing simulation measures, crucial variables such as the distance between machines, production time at each working station, the number of workers, and the factory layout were systematically considered.

Moreover, the researchers recognized the inherent uncertainties and temporal variations within the system, leading to the identification of stochastic inputs. To capture the dynamic nature of these inputs, distributions were derived through on-site data collection, specifically focusing on noodle orders and Inter-Arrival Time. Leveraging the Plant Simulation's built-in data fitting module, the team optimized the fitting of these distributions. Consequently, all process and transfer times within the factory were seamlessly integrated as probabilistic inputs, ensuring a comprehensive and realistic representation within the simulation model.

In framing their simulation model, the researchers also articulated key assumptions that underpin the model's realism. Notably, we assumed that workers, on average, take three breaks, deviating from the rigid schedules commonly found in real-world systems where workers take numerous mini breaks. Additionally, a foundational assumption posited that the source of noodles consistently propels them through the system, contributing to the intricate dynamics of the simulated noodle production environment.

2.8 Model verification and validation

Upon the completion of the noodle production process model, the next crucial phase involves verifying and validating its functionality. This entails running the model to ensure its smooth operation without encountering any program-related warning errors. Moreover, the model's behavior must align accurately with the actual working conditions observed within the case study factory, affirming its realism. To verify the model's credibility, a comprehensive reasonableness check was performed, deploying Minitab, a dedicated software tool for data analysis and statistical processing.

To validate the model, it was ensured that this model followed each logically possible action a system can take, derived from the data attained from the facility personnel. The team systematically went through every step or process in the model, ensuring its logical equivalence to the real system in real life. After the 8-hour shift simulation run time and 30 replications, the model resulted in a throughput approximately close to the throughput from the real system. Therefore, the team was sure that their simulated model was a very close replication of real life, providing robust verification and validation, and we could continue the experiment of changing the model environment to show how each factor affects the throughput.

2.9 Idea for formulating alternative solutions

Through a comprehensive analysis of the VSM data, coupled with insights garnered from the examination of the current operational model, a series of critical issues within the noodle production process came to light. These issues include:

1) Quality control challenges during steaming: The process of steaming the noodles presented significant difficulties in maintaining the desired quality standards, resulting in excessive waste exceeding predefined targets.

2) Quality control concerns during packing: The packing stage, encompassing weighing procedures, emerged as an area fraught with quality control challenges. This issue manifested as variations in the weights of individual product bags, adversely affecting consistency.

3) Quality control hurdles in packaging and vacuum sealing: The packaging and vacuum-sealing segment of the production process not only exhibited a lack of quality control but also faced issues related to process efficiency. This, in turn, led to bottlenecks within the overall production process.

Faced with these critical challenges, the research endeavor embarked on a strategic exploration, contemplating four distinct avenues for improving the noodle production process by harnessing the potential of IoT and automation technologies. These options were meticulously considered, with the objective of optimizing the production process and addressing the identified quality control and efficiency issues, as detailed in the subsequent sections.

2.9.1 Alternative ideas to solve problems with IoT

1) Rationale for technology integration

Scenario 1: The decision to integrate IoT into the steaming process stems from the critical need to address quality control challenges. The precise control facilitated by Programmable Logic Controllers (PLC), combined with sensors monitoring temperature, pressure, and moisture levels, directly tackles inefficiencies observed in conventional steaming. This choice is driven by the desire to enhance moisture reduction, subsequently reducing drying time and elevating noodle quality to meet stringent production standards.

Scenario 2: Similar to Scenario 1, the integration of IoT in the noodle steaming process is motivated by a commitment to quality improvement. The comprehensive approach, involving control valves, flow meters, and sensors, is strategically chosen to ensure automated regulation of the boiler system. This automation guarantees precise control over pressure, temperature, and humidity, resulting in a significant uplift in noodle quality and operational efficiency. The decision is guided by the intent to align the production process with rigorous quality control standards and enhance overall process efficiency.

2) Technical specifications

Scenario 1: The integration of IoT in the steaming process utilizes advanced technologies such as Programmable Logic Controllers (PLC) and pressure-temperature sensors. These PLC systems offer a high degree of control over valves and conveyor belts, contributing to effective moisture reduction. The pressure-temperature sensors play a pivotal role in real-time monitoring and regulation, ensuring optimal steaming conditions.

Scenario 2: the technical specifications involve a sophisticated combination of control valves, flow meters, pressure-temperature sensors, and Human-Machine Interface (HMI) integrated into the control panel. This setup enables automated regulation of the boiler system, providing precise control over critical parameters. The inclusion of PLC and HMI enhances the user interface and overall system control.

3) Integration workflow

Scenario 1: The workflow begins with the PLC systems receiving data from pressure-temperature sensors. Based on this data, the PLC regulates valves, conveyor belts, and other components to achieve optimal steaming conditions. The seamless interaction among these elements ensures a synchronized and efficient steaming process (as shown in Figure 4).

Scenario 2: Involves a more comprehensive integration workflow, where control valves, flow meters, and pressure-temperature sensors collaborate to regulate the boiler system. The PLC and HMI play a central role in orchestrating these interactions, ensuring precise control over pressure, temperature, and humidity. This integrated workflow enhances the overall efficiency of the noodle steaming process (as shown in Figure 5).

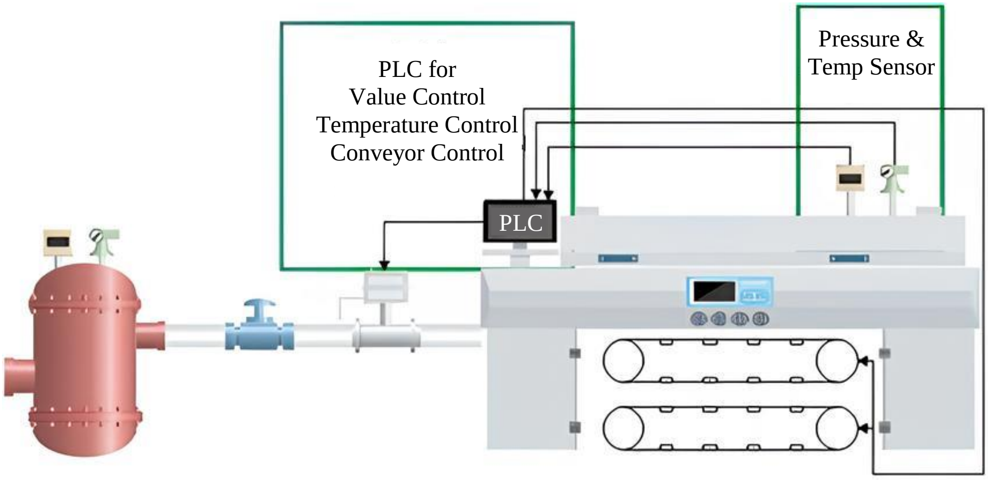

Figure 4 Integration of IoT technology utilizing PLC systems and pressure - temperature sensors in the noodle steaming process.

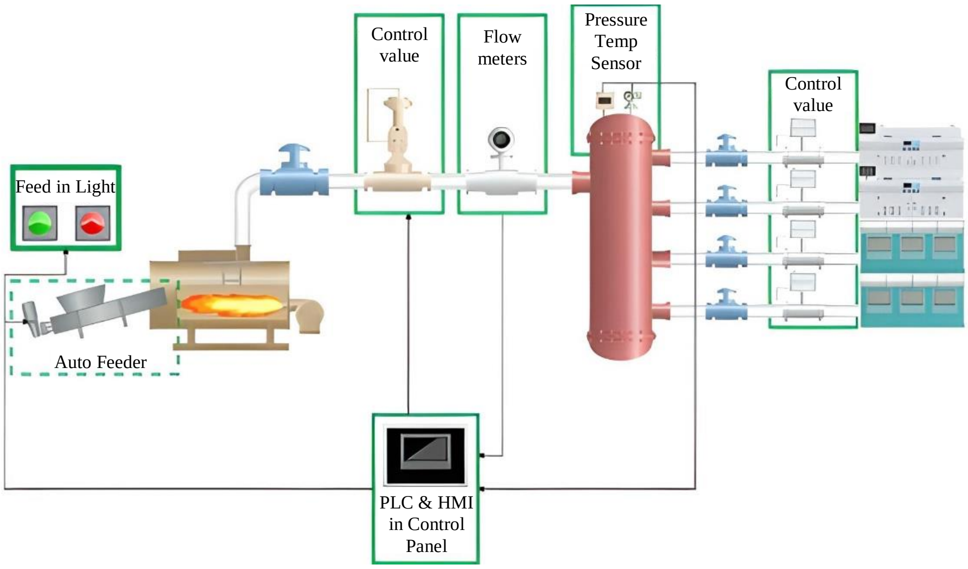

Figure 5 Integration of IoT applications for controlling boilers with control valves, flow meters, pressure-temperature sensor, PLC, and HMI.

4) Expected benefits

Scenario 1: The integration of IoT in Scenario 1 anticipates significant benefits, including more effective moisture reduction, reduced drying time, and notably improved noodle quality. The automated control facilitated by IoT technologies aims to address and mitigate quality control challenges observed in conventional steaming processes.

Scenario 2: The expected benefits revolve around enhanced noodle quality and operational efficiency. The precise control over the boiler system, achieved through IoT integration, is projected to result in a substantial improvement in product quality. Additionally, the automated regulation of critical parameters contributes to overall process efficiency.

5) Alignment with quality standards

Scenario 1: The integration of IoT in Scenario 1 aligns with quality control standards by addressing specific challenges related to moisture reduction and drying time. The goal is to elevate noodle quality to meet or exceed industry standards, ensuring that the production process adheres to rigorous quality control requirements.

Scenario 2: Similarly, Scenario 2 aligns with quality control standards by focusing on precise control over pressure, temperature, and humidity in the noodle steaming process. The anticipated enhancement in noodle quality positions the production process to meet stringent quality standards, demonstrating a commitment to delivering high-quality products.

2.9.2 Alternative ideas to solve problems with automation

1) Rationale for automation integration

Scenario 3: The integration of automation in the weighing and packaging process aims to address precision and efficiency challenges. By incorporating an automatic weighing scale on the conveyor belt, the objective is to achieve uniform weight distribution in each bag, aligning with quality control standards and customer expectations. This automation not only reduces errors and inconsistencies but also enhances resource utilization and overall process efficiency, contributing to improved product quality and customer satisfaction.

Scenario 4: Introduces an automation-driven approach to enhance the noodle packing process. The incorporation of a horizontal automatic sealing machine is designed to improve the time efficiency of the process, reducing the duration required for sealing vacuum bags—a crucial step in production. This automation leads to an enhanced speed in the packing process, resulting in a more rapid and responsive production system. The increased throughput enables the company to meet customer demand more effectively while minimizing lead times, contributing to overall operational efficiency and customer satisfaction.

2) Technical specifications

Scenario 3: The technical specifications in Scenario 3 involve the integration of an automatic weighing scale on the conveyor belt. This automated system ensures uniform weight distribution in each bag by precisely measuring and regulating the weight of noodles. The incorporation of automation in this process minimizes errors, reduces waste, and enhances overall resource utilization.

Scenario 4: The technical specifications include the integration of a horizontal automatic sealing machine into the noodle packing process. This automation streamlines the sealing of vacuum bags, reducing the time required for this critical step. The automated sealing machine contributes to increased throughput, allowing the company to meet customer demand more efficiently.

3) Integration workflow

Scenario 3: The workflow in Scenario 3 begins with the automatic weighing scale on the conveyor belt measuring the weight of noodles. The automated system ensures uniform weight distribution in each bag by regulating the weight according to predefined standards. This integrated workflow enhances precision in the weighing and packaging process (as shown in Figure 6).

Scenario 4: Involves the integration of a horizontal automatic sealing machine into the noodle packing process. The workflow includes the automated sealing machine efficiently sealing vacuum bags. This automation-driven process reduces the time required for sealing, contributing to an overall enhancement in the packing process efficiency (as shown in Figure 7).

4) Expected benefits

Scenario 3: The integration of automation in Scenario 3 anticipates benefits such as enhanced precision in weighing, uniform weight distribution, and a reduction in errors and waste. The automated weighing scale contributes to improved resource utilization and overall process efficiency, leading to higher product quality and customer satisfaction.

Scenario 4: The expected benefits revolve around the improved time efficiency of the noodle packing process. The automation-driven integration of a horizontal automatic sealing machine enhances the speed of the packing process, resulting in a more responsive and efficient production system. The increased throughput contributes to meeting customer demand effectively.

5) Alignment with quality standards

Scenario 3: The integration of automation in Scenario 3 aligns with quality control standards by focusing on precision in weighing and uniform weight distribution. The automated system ensures that each bag meets predefined weight standards, contributing to the overall quality of the packaged noodles.

Scenario 4: Similarly, Scenario 4 aligns with quality control standards by improving the time efficiency of the noodle packing process. The automation-driven integration of the sealing machine contributes to a more efficient and responsive production system, meeting customer demand while maintaining high-quality standards.

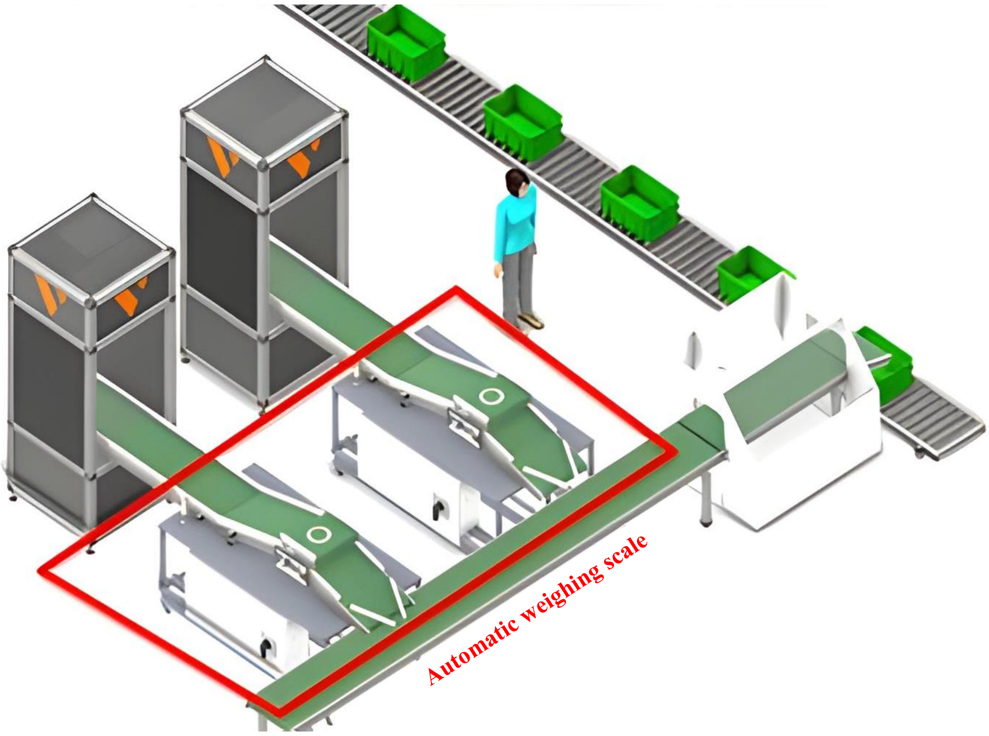

Figure 6 Integration of automatic weighing scale on the conveyor belt.

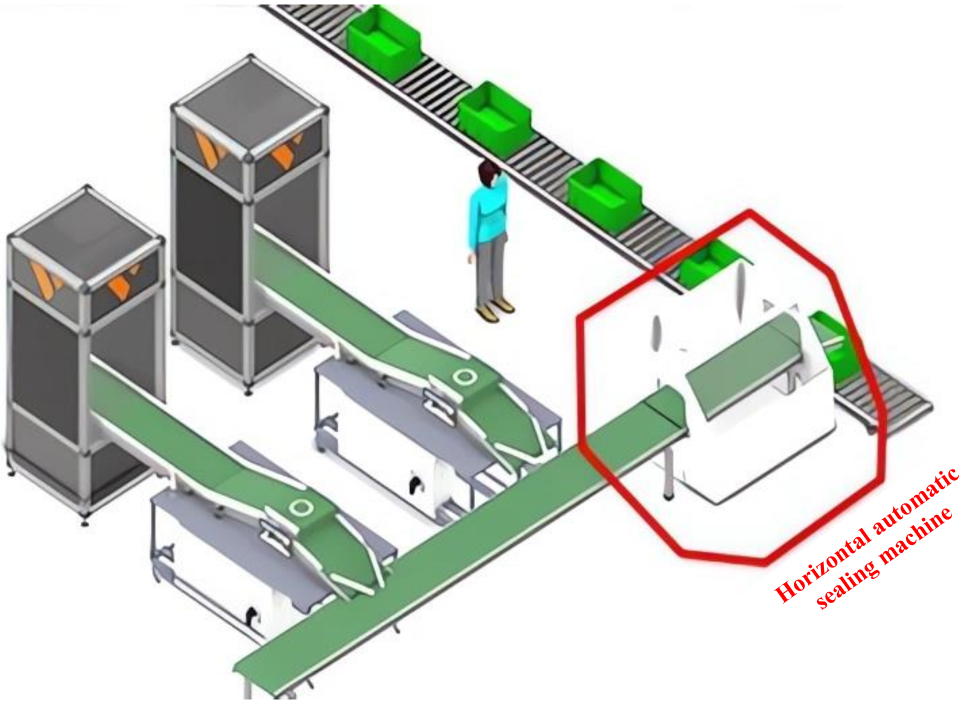

Figure 7 Integration of horizontal automatic sealing machine.

3. Results

3.1 Examination of operational bottleneck

Upon a comprehensive examination of the case study and rigorous data collection aimed at problem analysis and causal identification within the noodle production process, a pivotal issue came to light. It was revealed that the bottleneck process, pivotal in the overall operational workflow, was the packing process, resulting in a substantial time loss within the production process. Furthermore, the utilization of manpower exceeded optimal requirements, leading to unwarranted process waste. In response to these identified challenges, the researcher proposed a forward-thinking solution, leveraging the capabilities of IoT and automation to enhance the production process.

Applying Lean principles and utilizing a Lean tool, we generated various Yamazumi charts for the noodle production process, allowing us to analyze the distribution of Value Added (VA), Non Value Added (NVA), and Non Value Added Necessary (NVAN) percentages within each simulation model.

As illustrated in Figure 8, the present Yamazumi chart provides a comprehensive overview of the process, indicating that 55% of the activities contribute value according to Lean principles. Additionally, 19% of the activities fall under the category of non-value-added activities, while 27% are deemed necessary despite not directly adding value to the final product. This breakdown offers valuable insights into the efficiency and optimization potential of the noodle production process, aligning with the continuous improvement principles of Lean and Kaizen.

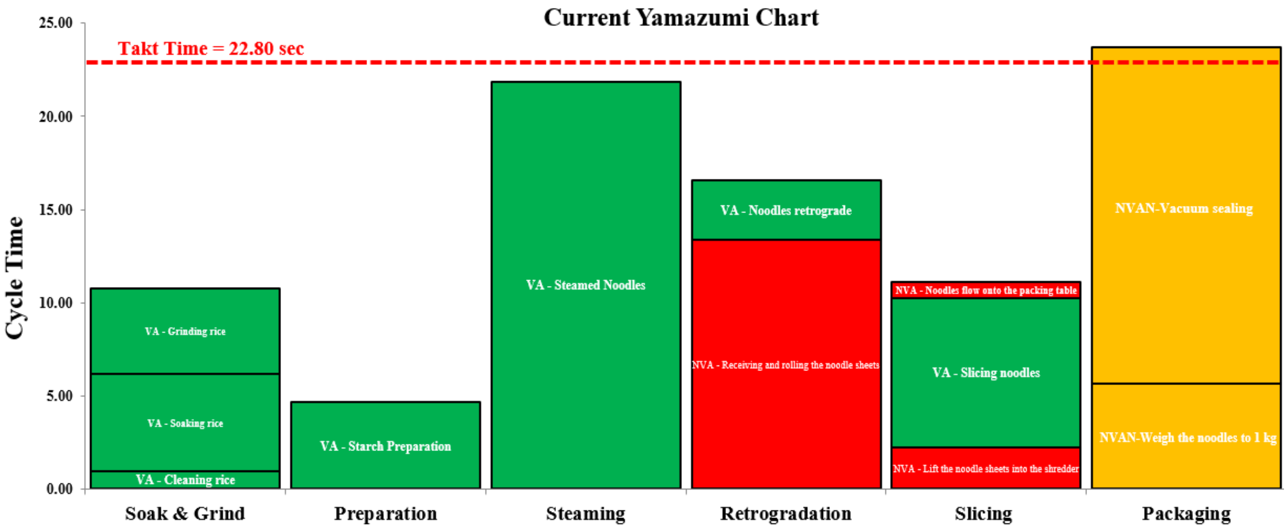

Figure 8 Current Yamazumi Chart

3.2 Comparative analysis of simulation scenarios

The research conducted a meticulous comparison between the results obtained from the existing production model and the four alternative improvement scenarios, as summarized in Table 3.

Scenario 1, which focuses on the integration of IoT technology employing PLC systems and pressure-temperature sensors in the noodle steaming process, yielded notable insights. This innovation led to a reduction in the required workforce, from 17 to 16 employees, while simultaneously reducing the cycle time for the steaming process by 2 sec, resulting in a decreased cycle time of 19.50 min. This change translated into a significant boost in production capacity, elevating it from 2,000 kg/day to 2,600 kg/day. Remarkably, Labor costs also saw a reduction, decreasing from 2.5 THB/kg to 2 THB/kg. However, the implementation of this technology did necessitate an initial investment of 650,000 THB, with a swift payback period of merely 0.35 years, indicating the potential for rapid returns on investment.

Scenario 2: Leveraging IoT Applications for boiler control, in the pursuit of enhancing operational efficiency, the outcomes of this implementation yielded compelling results. The scenario exhibited a reduction in the required workforce from 17 employees to 16, mirroring the findings of Scenario 1. Moreover, the cycle time for the steaming process was optimized, reducing it by 2 sec. to reach 19.50 min. This efficiency gain contributed to a remarkable increase in the production capacity of noodles, elevating it from 2,000 kg/day to 2,688 kg/day. Labor costs also saw a reduction, plummeting from 2.5 THB per kg to 2 THB/kg. However, the adoption of this sophisticated technology necessitated an initial investment of 1,000,000 THB, with a slightly extended but still favorable payback period of 0.54 years, indicating its potential for yielding substantial returns on investment. This elaboration provides an in-depth explanation of Scenario 2, emphasizing the technological components and the improvements in production capacity, labor costs, and payback period.

Scenarios 1 and 2 prioritize improvements in the steaming process rather than the packaging process. While these scenarios may not directly reduce the cycle time below the takt time, the factory team considers enhancing the steaming process as a critical improvement. You can emphasize that the objective of these scenarios is to address specific challenges in the steaming phase, contributing to overall process efficiency and quality.

Scenario 3 marked a significant step towards operational enhancement by introducing an innovative solution - the integration of an automatic weighing scale onto the conveyor belt. This strategic adoption translated into compelling outcomes. Firstly, the workforce required for the noodle production process experienced a notable reduction, from 17 employees to 14, highlighting the efficiency of this technological innovation. The cycle time of the packing process witnessed substantial improvement, decreasing by 5.4 sec, and culminating in a cycle time of 18.30 min. This process optimization was instrumental in elevating the production capacity of noodles, achieving an impressive upsurge from 2,000 kg/day to a remarkable 4,760 kg/day. Simultaneously, labor costs saw a significant decline, plummeting from 2.5 THB/kg to 1.5 THB/kg, reaffirming the financial advantages of this integration. Notably, an investment of 1,000,000 THB was required for the initial purchase of the system, with a favorable payback period of 0.53 years. These results underscore the potential of this solution in not only streamlining operations but also delivering substantial returns on investment." This detailed explanation provides a thorough insight into Scenario 3, highlighting the workforce reduction, improvements in cycle time and production capacity, and the associated labor cost reduction, alongside the investment and payback period details.

Scenario 4 ushered in a transformation through the integration of a horizontal automatic sealing machine, leading to noteworthy outcomes. Workforce optimization reduced the operational team from 17 employees to 15. The packing process witnessed a remarkable cycle time reduction of 4.22 seconds, resulting in a 19.48 -min cycle time. This refinement significantly increased noodle production capacity from 2,000 kg/day to an impressive 4,500 kg/day. Simultaneously, labor costs decreased from 2.5 THB/kilogram to 1.5 THB/kg. The initial system investment was 500,000 THB, with a remarkably short payback period of just 0.27 years. These results highlight the operational and financial advantages of integrating a horizontal automatic sealing machine, underscoring its role in enhancing efficiency and profitability.

Table 3 Comparative Outcomes of the Four Simulation Strategies

	IoT		**Automation**	
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Number of labor	16	16	14	15
Cycle time (sec)	19.5 (Streaming)	19.5 (Streaming)	18.30 (Packaging)	19.48 (Packaging)
Capacity / Day	2,600	2,688	4,760	4,500
Labor cost/kg	2.5	2.5	1.5	1.5
Investment Cost (THB)	650,000	1,00,000	1,00,000	500,000
Payback Period (years)	0.35	0.54	0.54	0.27

3.3 Management's scenario approval

In the organizational context, the business owner and key team members approved scenario 1 and scenario 4 due to their potential to reduce total production time and enhance operational efficiency. These scenarios offered a strategic response to increased customer demand while maintaining an optimal investment balance. This approval underscores the organization's commitment to efficiency, productivity, and competitive advantage.

3.4 Prospective cycle times and productivity in the noodle production process

Following the rigorous simulation exercises, the noodle production process has undergone a strategic realignment. While the total number of workstations, standing at 6, remains consistent with the initial setup, significant refinements have been introduced, particularly in the steaming and packaging stages. These adjustments have not only streamlined the workflow but have also led to noteworthy enhancements in the process's efficiency. Table 3 serves as a visual representation of this post-improvement landscape, providing a comprehensive breakdown of the workflow and standard time allocated to each workstation. This insight into the refined process structure and the associated time metrics offers a detailed view of how technology-driven enhancements can revolutionize production dynamics, ultimately advancing the industry's potential for operational excellence.

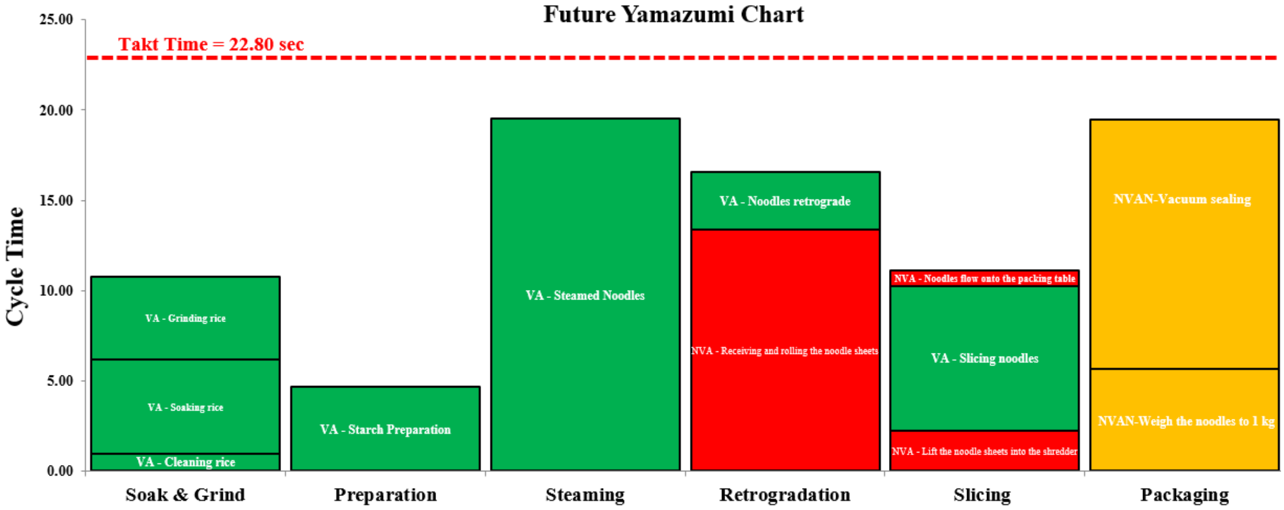

Figure 9 Future Yamazumi Chart

Table 4 offers an illuminating visual representation, akin to the depiction seen in Figure 9, showcasing the cycle time allocations within the noodle production process following the introduced enhancements. This transformation has resulted in the optimal organization of six distinct workstations, each contributing to the streamlined production of noodles. Notably, these improvements culminate in a noteworthy reduction in the actual cycle time, now standing at 19.5 sec/kg, primarily attributed to the efficiency gains in the steaming station, which previously presented a bottleneck. Furthermore, as depicted in Table 4, the overall substation time now amounts to 82.08 sec/kg, underscoring the substantial improvements in workflow. These refinements enable the calculation of the enhanced productivity of the noodle production line, reflecting a commendable 70.15%. The future Yamazumi chart, which represents a 56% of value added activities, a 20% of non value added and a 24% of non value added but necessary activities. This marked increase in productivity speaks to the far-reaching implications of leveraging technology-driven solutions, not only in streamlining operations but also in significantly enhancing the overall efficiency and productivity of the noodle manufacturing process. These findings underscore the real-world applicability of these enhancements, redefining industry standards and paving the way for operational excellence.

Table 4 Production process and future cycle times at each workstation for noodle production

Workstation	Name	Process	Cycle time (sec)	
1	Soak & Grind	Cleaning rice	0.94	10.74
		Soaking rice	5.24	
		Grinding rice	4.56	
2	Preparation	Starch Preparation	4.65	4.65
3	Steaming	Steamed Noodles	19.50	19.50
4	Retrogradation	Receiving and rolling the noodle sheets	13.35	16.59
		Noodles retrograde	3.24	
5	Slicing	Lift the noodle sheets into the shredder	2.21	11.12
		Slicing noodles	8.02	
		Noodles flow onto the packing table	0.89	
6	Packaging	Weigh the noodles to 1 kg	5.64	19.48
		Vacuum sealing	13.84	
			Total	**82.08**

3.5 Future state map

At the heart of lean production lies a core objective: the identification and elimination of waste to minimize process costs. This journey begins with a meticulous analysis of the current state through Value Stream Mapping (VSM) and culminates in the visualization of a future state (Figure 10). This vision incorporates essential modifications, aiming to eliminate non-value-added kaizen activities in the process. The integration of IoT in the steaming process (Scenario 1) and automation in the packaging phase (Scenario 4) exemplify this approach, offering a streamlined and efficient pathway toward operational excellence.

4. Discussion

In this section, we compare the findings of our study with those of relevant academic articles. By examining the convergence and divergence of our results with existing research, we gain deeper insights into the implications of technology-driven enhancements in the context of food manufacturing.

Scenario 1 and Scenario 2: Integration of IoT technology for steaming process optimization, our research has demonstrated a substantial increase in production capacity by 76% through the implementation of IoT technology in the steaming process [21]. These outcomes align with the findings of Wójcicki et al. [22], where a similar adoption of IoT led to a 75% rise in production capacity. These consistent results suggest a robust relationship between IoT technology and enhanced production capacity.

Scenario 3 and Scenario 4: Automation in weighing and packaging processes, the cost-effectiveness of automation and IoT solutions in reducing labor costs and improving efficiency is evident in our study [23]. These findings closely correspond with the research by Dinlersoz and Wolf [24], where automated solutions resulted in a 40% reduction in labor costs and a swift payback period. The parallel outcomes underscore the universal applicability of automation and IoT in optimizing operational efficiency across food manufacturing industries.

Reduction in cycle time: Our research focuses on the reduction of cycle time in the noodle production process, leading to substantial efficiency gains [25]. In a related study by Ito et al. [26], the incorporation of technology-driven solutions, including IoT and automation, yielded an average reduction in cycle time. It reaffirms the notion that the integration of technology can lead to substantial reductions in cycle time.

Implications of Our Findings: Our research highlights the transformative potential of technology-driven enhancements in the Noodle Production Process of the Thai Food Industry. Notably, the substantial increase in production capacity, cost-effectiveness in labor utilization, and efficiency gains underscore the effectiveness of integrating Lean-Kaizen principles alongside IoT and automation solutions. These findings hold broader implications for the food manufacturing sector, suggesting that similar technology-driven approaches can lead to enhanced productivity, reduced costs, and improved operational efficiency.

Challenges and Limitations: While our study contributes valuable insights, it is crucial to acknowledge its limitations. The specific contextual factors of the Thai food industry may impact the generalizability of our findings to other manufacturing settings. Furthermore, the study's scope may not encompass all potential challenges and variations in different operational contexts. Recognizing these limitations is essential for interpreting the study's results and guiding future research.

Directions for Future Research: To advance our understanding, future research should explore the scalability and adaptability of technology-driven solutions across diverse food manufacturing contexts. An in-depth investigation into potential implementation challenges, barriers, and the exploration of emerging technologies will be crucial for addressing the evolving landscape of technology in food production.

These comparative discussions emphasize the consistency and applicability of technology-driven solutions in improving efficiency, productivity, and cost-effectiveness across food manufacturing sectors, while also highlighting the robustness of our study's findings.

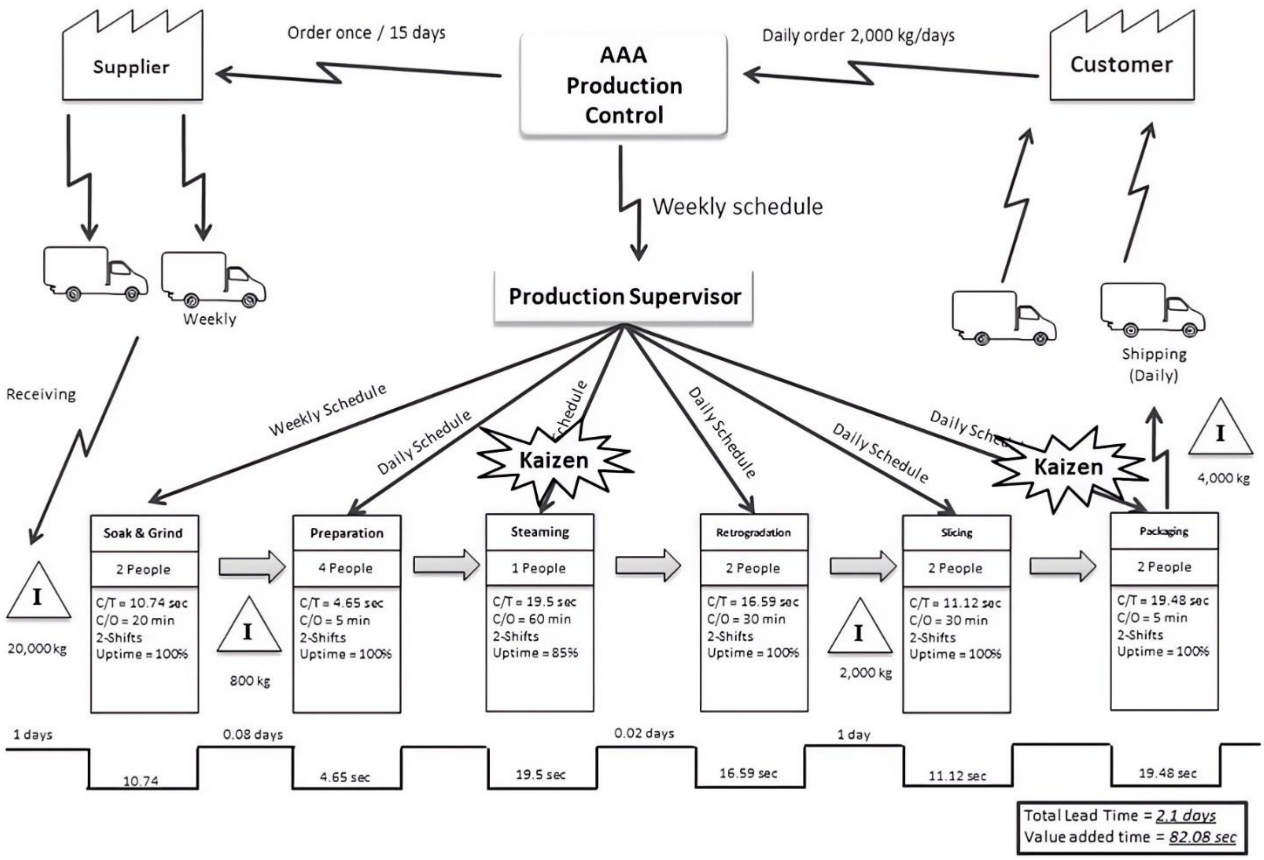

Figure 10 Future state map

5. Conclusions

In conclusion, this research underscores the transformative impact of technology on the Noodle Production Process in the Thai Food Industry. The integration of Lean-Kaizen principles with IoT and automation solutions has yielded significant improvements. Specifically, Scenarios 1 and 2, incorporating IoT into the steaming process, demonstrated a remarkable 76% increase in production capacity, translating to a noteworthy reduction in cycle time by 2 sec/kg. Meanwhile, Scenarios 3 and 4, focusing on automating weighing and packaging, not only proved cost-effective but also resulted in substantial reductions in labor costs, with a short payback period of 0.53 years, highlighting their feasibility and efficiency.

The overarching theme of reducing cycle time, a central focus of our research, aligns with broader industry trends. The incorporation of technology-driven solutions, such as IoT and automation, holds significant potential in effectively addressing production challenges and enhancing overall efficiency within the food manufacturing sector.

However, it is essential to acknowledge the limitations of our research. The specific context of the Thai food industry may restrict the generalizability of our findings to other manufacturing settings. Additionally, while our study delves into significant aspects of production optimization, it may not encompass all potential variables and challenges that could impact broader applications.

As we look to the future, there is a need for more in-depth investigations into the nuanced implementation of these technologies. Future research endeavors should explore additional scenarios, assessing their implications on different aspects of food manufacturing processes. Moreover, a comprehensive exploration of potential scalability, adaptability to diverse production settings, and the integration of emerging technologies will be crucial for staying at the forefront of innovation in the dynamic landscape of food production. By delving into these areas, researchers can contribute valuable insights that further propel the industry toward operational excellence.

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We extend our sincere appreciation to the company that participated in this study. Their invaluable cooperation, dedication, and open collaboration in providing access to the work site and implementing recommended modifications were instrumental in the successful execution of our research objectives. This partnership enabled us to gather real-world data, tour the work site, and iteratively refine work methods until the desired goals were achieved.

The synergy between research and industry is crucial, and this project exemplifies the positive outcomes that can be realized when academia and the private sector collaborate toward a common vision.

7. References

[1] Maroli A, Narwane VS, Gardas BB. Applications of IoT for achieving sustainability in agricultural sector: a comprehensive review. J Environ Manag. 2021;298:113488.
[2] da Costa TP, Gillespie J, Cama-Moncunill X, Ward S, Condell J, Ramanathan R, et al. A systematic review of real-time monitoring technologies and its potential application to reduce food loss and waste: key elements of food supply chains and IoT technologies. Sustainability. 2023;15(1):614.
[3] Heema R, Sivaranjani S, Gnanalakshmi KS. An insight into the automation of the dairy industry: a review. Asian J Dairy Food Res. 2022;41(2):125-31.
[4] Zúñiga ER, Moris MU, Syberfeldt A, Fathi M, Rubio-Romero JC. A simulation-based optimization methodology for facility layout design in manufacturing. IEEE Access. 2020;8:163818-28.
[5] Maware C, Okwu MO, Adetunji O. A systematic literature review of lean manufacturing implementation in manufacturing-based sectors of the developing and developed countries. Int J Lean Six Sigma. 2022;13(3):521-56.
[6] Ortiz ORD, Cárdenas GAM. Kaizen methodology: literature review and implementation analysis. J Sci Technol Res Ind. 2022;3(2):26-35.
[7] Rejeb A, Simske S, Rejeb K, Treiblmaier H, Zailani S. Internet of things research in supply chain management and logistics: a bibliometric analysis. Internet of Things. 2020;12:100318.
[8] Firouz MS, Mohi-Alden K, Omid M. A critical review on intelligent and active packaging in the food industry: research and development. Food Res Int. 2021;141:110113.
[9] Jiang W. An intelligent supply chain information collaboration model based on Internet of Things and big data. IEEE Access. 2019;7:58324-35.
[10] Abdelmegid MA, González VA, O'Sullivan M, Walker CG, Poshdar M, Alarcón LF. Exploring the links between simulation modeling and construction production planning and control: a case study on the last planner system. Prod Plan Control. 2023;34(5):459-76.
[11] Tyagi T, Kumar S, Malik AK, Vashisth V. A novel neuro-optimization techniques for inventory models in manufacturing sectors. J Comput Cogn Eng. 2023;2(3):204-9.
[12] Liu L, Zhao T, Xie Y, Qiu X, Liu S, Wei S, et al. Research on production simulation and bottleneck identification for intelligent printing plant. J Imaging Sci Technol. 2023;67(2):1-7.
[13] Issa TN. Implementing lean-kaizen for manufacturing operations improvement: a case-study in the plastics industry. Int J Ind Syst Eng. 2023;44(1):118-39.
[14] Maware C, Okwu MO, Adetunji O. A systematic literature review of lean manufacturing implementation in manufacturing-based sectors of the developing and developed countries. Int J Lean Six Sigma. 2022;13(3):521-56.
[15] Abbasi R, Martinez P, Ahmad R. The digitization of agricultural industry–a systematic literature review on agriculture 4.0. Smart Agric Technol. 2022;2:100042.
[16] Bigliardi B, Bottani E, Filippelli S. A study on IoT application in the Food Industry using Keywords Analysis. Procedia Comput Sci. 2022;200:1826-35.
[17] Wang J, Qu Z. Design of intelligent weighing and picking system based on sensing technology. Acad J Manag Soc Sci. 2023;2(3):86-9.
[18] Caldwell DG. Automation in food manufacturing and processing. In: Nof SY, editor. Springer Handbook of Automation. Cham: Springer; 2023. p. 949-71.
[19] Nshirim ES, Nwagwu U. Integrated approach for process improvement: value engineering, lean methodology, SIPOC, and value stream mapping. Int J Appl Nat Sci. 2023;1(1):58-66.
[20] Wang CN, Chau Vo TTB, Chung YC, Amer Y, Truc Doan LT. Improvement of manufacturing process based on value stream mapping: a case study. Eng Manag J. 2023:1-19.
[21] Adeleke I, Nwulu N, Adebo OA. Internet of Things (IoT) in the food fermentation process: a bibliometric review. J Food Process Eng. 2023;46(5):e14321.

[22] Wójcicki K, Biegańska M, Paliwoda B, Górna J. Internet of Things in industry: research profiling, application, challenges and opportunities—a review. Energies. 2022;15(5):1806.
[23] Seetha J, Senthil Kumar S, Nruthya K, Rao NKK, Leela Rani D. Enhancement of agriculture productivity and automation of agriculture using IoT. 2023 International Conference on Inventive Computation Technologies (ICICT); 2023 Apr 26-28; Lalitpur, Nepal. USA: IEEE; 2023. p. 1411-7.
[24] Dinlersoz E, Wolf Z. Automation, labor share, and productivity: plant-level evidence from U.S. manufacturing. Econ Innov New Technol. 2023:1-23.
[25] Silitonga RM, Jou YT, Lin MC. Reducing defect products in instant noodles production with Six Sigma. AIP Conf Proc. 2023;2485:120016.
[26] Ito T, Abd Rahman MS, Mohamad E, Abd Rahman AA, Salleh MR. Internet of things and simulation approach for decision support system in lean manufacturing. J Adv Mech Des Syst Manuf. 2020;14(2):1-12.